Horizontal to vertical spectral ratio measurements in Port-au-Prince (Haiti) area damaged by the 2010 Haiti earthquake.

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SUMMARY

In order to evaluate ground shaking characteristics due to surface soil layers in the urban area of Port-au-Prince, short-period ambient noise observation has been performed approximately in a 500x500m grid. The HVSR method was applied to this set of 36 ambient noise measurement points to determine a distribution map of soil predominant periods. This map reveals a general increasing trend in the period values, from the Miocene conglomerates in the northern and southern parts of the town to the central and western zones formed of Pleistocene and Holocene alluvial deposits respectively, where the shallow geological materials that cover the basement increase in thickness. The shallow shear-wave velocity structure at the National Palace place has been estimated by means of inversion of Rayleigh wave dispersion data obtained from vertical-component array records of ambient noise. Three regular pentagonal arrays were used with 5, 10 and 20m radii. Reliable dispersion curves were retrieved for frequencies between 4.0 and 14 Hz, with phase velocity values ranging from 420m/s down to 270 m/s. Finally, the average shear-wave velocity of the upper 30 m (V_S^{30}) was inverted for site characterization.

INTRODUCTION

The 2010 Haiti earthquake, occurred on January 12th at 16:53:09 local time (21:53:09 UTC) with epicentral distance of 15 km from the capital Port au Prince, M_W 7.0 and 13 km hypocenter deep. The maximum macroseismic intensity was estimated as X (MMI scale) by the U.S. Geological Survey (USGS). This earthquake was the strongest event recorded in the area since happened in 1770 (Figure 1).

In December 2010, a Spanish cooperation project started with a clear objective: Evaluation of seismic hazard and risk in Haiti and its application to the seismic design, urban planning, emergency and resource management. One of the tasks of the project was to analyse the characteristic response of the local shallow structure in Port-au Prince by means of ambient vibration measurements.

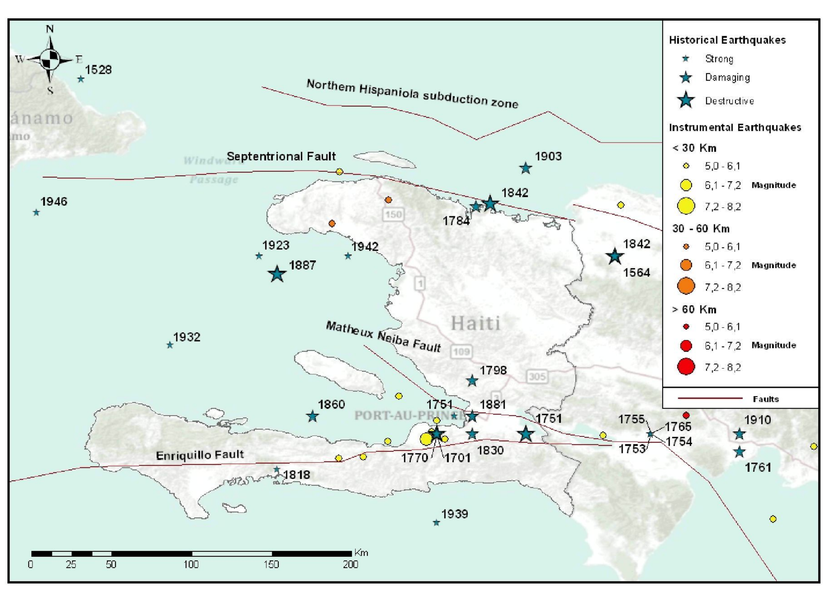

Figure 1. Distribution of seismicity (M>5.0) and main fault systems. Main historical earthquakes are represented with stars.

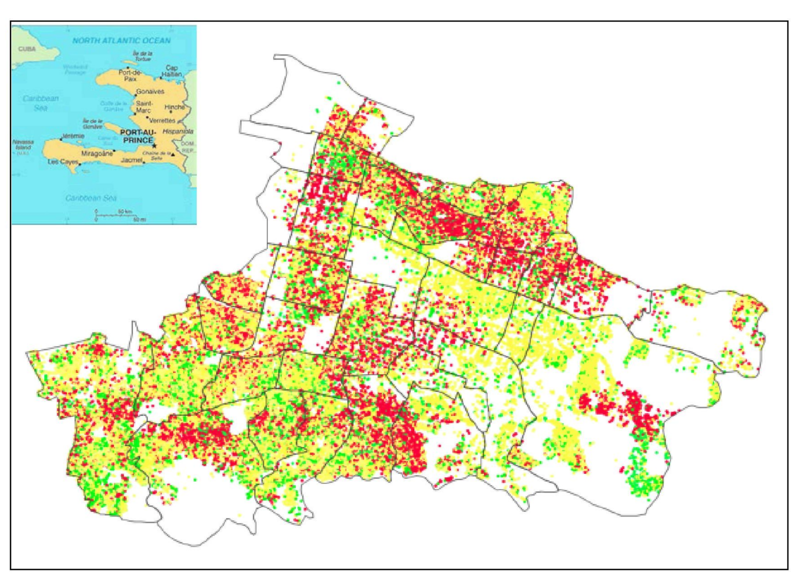

Figure 2. Damage distribution in Port-au-Prince due January 12th, 2010 Haiti earthquake.

SOIL PREDOMINANT PERIOD

HVSR method (Nakamura 1989) was used to determine the predominant period of soil. Ambient vibration measurements in the urban area of Port-au-Prince town were recorded at 36 places approximately located on a 500x500 m grid. The signal processing was carried out following García-Jerez et al (2006), including the use of time-dependent plots (Almendros et al., 2004) for stability control.

A single horizontal spectrum was generated using geometrical average of two horizontal spectra, and HVSR is separately computed for 20s long time windows and plotted in a time-dependent diagram (ratiogram). Finally, the horizontal-to-vertical ratios are averaged over the good quality time periods. As examples, the HVSRs for several places are shown in Fig. 3. Subsequently, a map of the predominant period spatial distribution at the urban area of Port-au-Prince was prospected (Fig. 4) to establish a preliminary seismic microzonation in terms of resonance periods of surface geology.

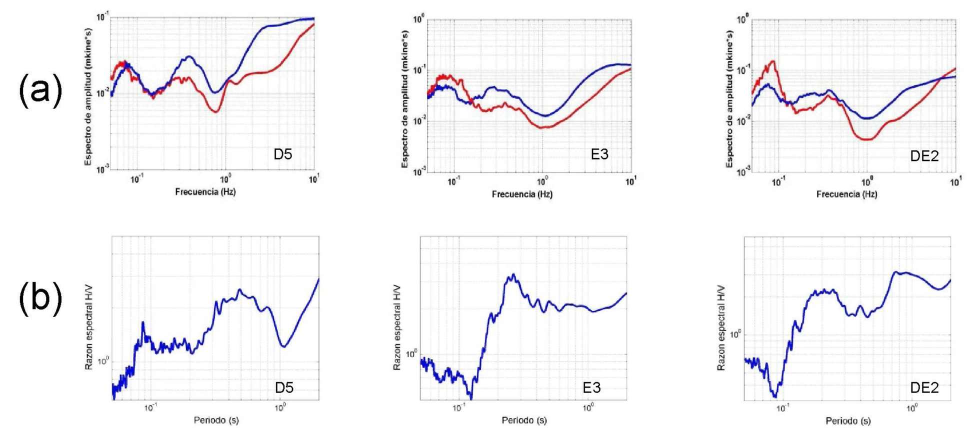

Figure 3. a) Examples of amplitude Fourier spectrum: Vertical component (red color) and horizontal component (blue color); b)Examples of spectral ratio in different places of Port-au-Prince town with different soil conditions.

Figure 4. Predominant period distribution map in Port-au-Pince from ambient vibration data analysis.

SHEAR-WAVE VELOCITY STRUCTURE

The shallow structure was analyzed at one site located into National Palace using the Spatial Autocorrelation method (SPAC). The S-wave velocity profile has been obtained by means of inversion from the Rayleigh wave dispersion curve. Vertical components of soil motion, excited by ambient vibration, were recorded using circular-shaped arrays. Three different radii of 5, 10 and 20m were used.

In order to obtain the correlation coefficient ρ(f,R), the cross correlations between records on the circle and the central station were calculated in frequency domain (Fig. 5a). Then, the phase-velocity of the Rg-wave c(f) was computed for each frequency f (Fig. 5b).

A ground structure consisting of plane-horizontal homogeneous layers overlying a half-space, defined in terms of Shear-wave velocities, was obtained by inversion of Rg-wave phase-velocity dispersion curves for the sample site. The suitable initial ground model required by the iterative inversion scheme used was built up from the dispersion curve following the λ/3 penetration criterion (Tokimatsu, 1997). The result shows a structure (Fig. 5c) with shear-wave velocity values ranging between 233 m/sec and 501 m/sec.

The fundamental resonance period of the inverted model for vertically incident S waves matches well the experimental value of 0.33 sec. calculated from H/V spectral ratio (Fig. 5d).

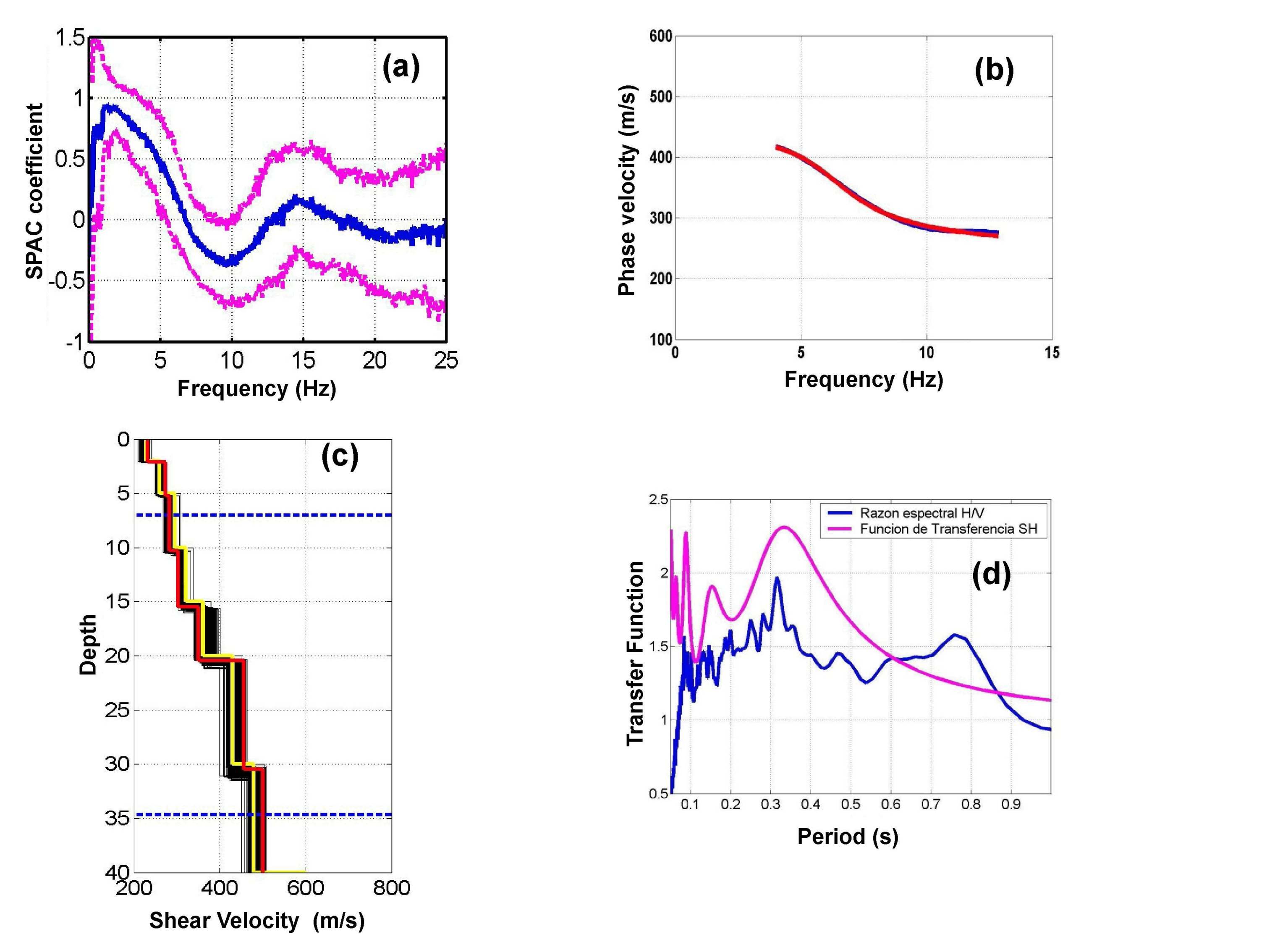

Figure 5. Analysis process for determining the shear-wave velocity structure at National Palace: (a) SPAC coefficient for a radius of 20 m; (b) Smoothed fundamental-mode Rg dispersion curve (blue colour) and theoretical dispersion curve (red color) obtained from Shear-wave velocity model; (c) Shear-wave velocity model (red colour) derived from inversion of phase velocities, initial model represented by yellow colour; (d) H/V spectral ratio (blue colour) and theoretical 1D-transfer function for the inverted model (pink colour).

CONCLUSIONS

The predominant period map of soil obtained from ambient noise HVSR method shows a very irregular distribution of values. This fact is consistent with the lateral heterogeneity of the subsurface soil conditions in the study area. The lowest values (<0.15s) predominate in the southern area of the city, composed of Miocene conglomerates. Highest values (> 0.45s) are found in the center and western parts of the city, composed of Pleistocene-Holocene alluvial deposits and anthropogenic artificial fillings reclaimed from the sea.

The average shear-wave velocity value of the upper 30 m (V_S^{30}) at the National Palace was computed. The value found for V_S^{30} was 331 m/sec. According to this value, the Holocene alluvial fan deposits in this place can be classified as class D, according to NEHRP (2003) soil classification. This result is in good agreement with V_S^{30} values obtained with MASW method (Cox et al. 2011).

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